Paper presented at Oceanology International 2002 Conference
5-8 March 2002, ExCeL, London, UK

ARGO 2002
PROGRESS TOWARDS A GLOBAL ARRAY OF PROFILING FLOATS

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ABSTRACT

Argo will be a global array of 3,000 free-drifting profiling floats that will measure the temperature and salinity of the upper 2,000 metres of the ocean. Global observations from Argo will provide significant benefits for operational oceanography (predictions of ocean conditions for use by the oceanographic and marine research and industry communities); seasonal forecasting (improved long-term forecasts of wet or dry seasons and better warning of the likelihood of floods and drought) and climate studies (detecting changes in the temperature and salinity of the oceans that are related to climate change).

Since its inception about 3 years ago, Argo has gained momentum with 13 nations, plus the European Commission, providing (or planning to provide) funding for floats. Global coverage with around 3,000 floats is anticipated by 2006. This paper outlines the international Argo project and progress made to date.

USE OF NEUTRALLY BUOYANT FLOATS BEFORE ARGO

The idea of using neutrally buoyant floats to measure sub-surface ocean currents was first developed in the mid-1950s by Stommel (1955) in the US and Swallow (1955) in the UK. These early floats were tracked acoustically and the SOFAR and RAFOS floats that evolved from them were used extensively in the 1970s and 80s. A brief history of neutrally buoyant floats is given by Gould (1999).

World Ocean Circulation Experiment (WOCE)

WOCE is a component of the World Climate Research Program (WCRP) and involved scientists in 30 countries in carrying out observations of the worlds oceans and developing global ocean models to assimilate these data. The measurement phase of WOCE lasted from 1990 to 1998 and required global coverage with sub-surface floats, along with other measurements. This precluded acoustic tracking and resulted in the development by Webb Research Corporation of the first-generation Autonomous Lagrangian Circulation Explorer (ALACE), Davis et al. (1992), and Profiling ALACE (PALACE) floats, Davis et al. 2001. A number of PALACE floats are still reporting data after 4 or 5 years of operation. The PALACE is a neutrally buoyant float that surfaces at regular intervals by inflating an external bladder (hence changing its volume and density), transmits its temperature/pressure data to the Argos satellite system (which also determines its position) before returning to its operating depth. WOCE produced an invaluable baseline dataset of global ocean properties, which led to improved estimates of ocean transports and variability and allowed many ocean currents to be mapped with an accuracy not previously achieved.

THE INCEPTION OF ARGO

With the development of models for real-time ocean analysis and forecasting and an increased awareness of the importance of the oceans for our climate, there is a greater need than ever before for ocean temperature and salinity profiles. Normally, these are provided by expendable bathy-thermograph (XBT) soundings from naval and merchant vessels, and sampling from research ships. Many of the data are from merchant vessels under the Ship of Opportunity Programme (SOOP), and so are mainly confined to shipping lanes. Large areas of the oceans, particularly in the southern hemisphere are poorly covered. This is illustrated by Figure 1 which shows the locations of temperature profiles, received at the Met Office via the World Meteorological Organization (WMO) Global Telecommunication System (GTS), during September 1999.

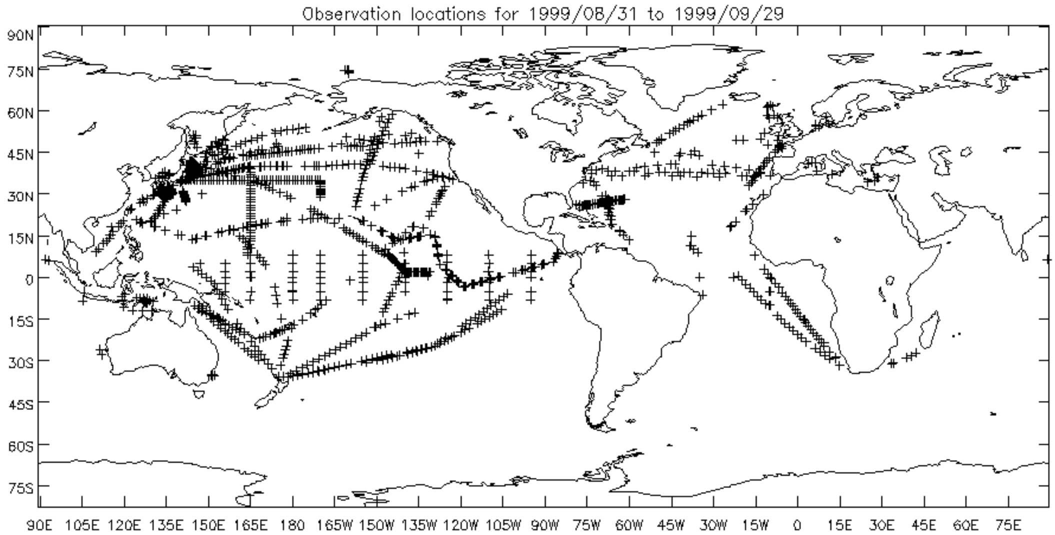

Figure 1. Locations of profile data received at the Met Office via GTS during September 1999.

WOCE provided a demonstration of the viability of using autonomous profiling floats to make global ocean measurements and provided the impetus for establishing a global array of profiling floats. Argo was proposed by the Ocean Observing Panel for Climate (OOPC), as a contribution to the GOOS (Global Ocean Observing System) and the GCOS (Global Climate Observing System), to provide continuous monitoring of the temperature and salinity of the upper ocean for use in real-time ocean prediction and ocean climate assessment.

The GOOS is conceived as a system for capturing data about the oceans and seas and for processing them, with other data, to provide beneficial services. The open ocean (climate) module of GOOS provides the oceanographic component of GCOS. GOOS and GCOS are co-sponsored by three UN bodies, the WMO, the Intergovernmental Oceanographic Commission (IOC) of UNESCO (United Nations Educational, Scientific and Cultural Organization), the United Nations Environment Programme (UNEP) and by the non-governmental organization, the International Council for Science (ICSU). Argo is also an important component of the GODAE (Global Ocean Data Assimilation Experiment - as discussed later) and WCRP CLIVAR (Climate Variability and Predictability) Programme.

In July 1998 a workshop, jointly convened by GODAE and CLIVAR, drew up an initial outline for Argo and appointed an Argo Science Team (AST) with responsibility for developing an implementation plan for Argo (Argo Science Team, 1998), and to provide scientific and technical guidance on float technology and establishment of the global array. Argo is described in Argo Science Team (1999), Wilson (2000) and by Roemmich and Owens (2000). The aim of Argo is to have approximately 3,000 floats deployed globally, with a spacing of about 300 km, as illustrated below.

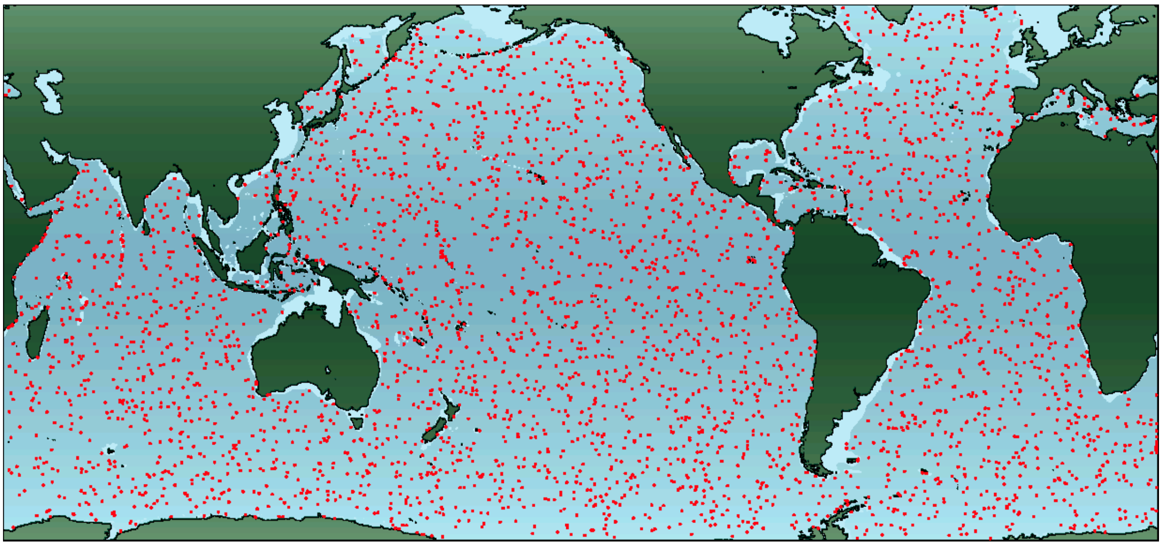

Figure 2. Illustrating the projected distribution of 3,000 profiling floats.

To achieve a 3,000 float array it will be necessary to deploy floats at a rate of about 825 per year (assuming 90% of the floats operate for 4 years and 10% fail early). Each float costs approximately US$25,000 over its 4 year life (including hardware, deployment and data management), such that the annual cost of maintaining a 3,000 float array is ~US$20 million. From the outset it was recognised that Argo was too large for any nation to undertake individually and would require a co-ordinated international effort; this began in early 1999 with the initial meeting of the AST. Since then 13 nations: Australia, Canada, China, Denmark, France, Germany, India, Japan, New Zealand, Republic of Korea, Spain, UK and USA have developed plans to provide floats, together with a contribution (Gyroscope) from the European Commission.

EXPECTED BENEFITS FROM ARGO

Operational oceanography

Argo will provide, in real-time, data on temperature and salinity of the upper ocean. The GODAE will bring together float data (Argo), satellite sea surface height data (e.g. from Jason) and ocean modelling to demonstrate the practicality and feasibility of routine, real-time high resolution (i.e. on eddy-resolving scales) global ocean data assimilation and prediction. GODAE is scheduled for 2003 to 2005, with an Atlantic pilot project planned for 2002 to exploit the fact that adequate float coverage in the North Atlantic is likely to be in place. A key component of GODAE will be the wide availability of ocean analyses and forecasts to participants and other potential users via the GODAE web-server.

Argo data are expected to lead to improved predictions from ocean models by (i) making it worthwhile to assimilate salinity data (little of which is currently available), (ii) allowing better initialisation of the upper ocean structure and improved mixed layer prediction, (iii) allowing better representation (in combination with satellite altimeter data) of the vertical structure on the mesoscale, and (iv) permitting better validation of the accuracy of predictions from operational ocean models.

Seasonal forecasting

The North Atlantic Oscillation (NAO) is a phenomenon associated with winter fluctuations in temperature, rainfall and storminess over much of Europe. When the NAO is 'positive', westerly winds are stronger or more persistent, northern Europe tends to be warmer and wetter than average and southern Europe colder and drier. When the NAO is 'negative', westerly winds are weaker or less persistent, northern Europe is colder and drier and southern Europe warmer and wetter than average. Observations indicate that there is a link between the NAO and North Atlantic SST.

Although it is generally not possible to predict individual weather events more than several days in advance, it is possible to provide useful information about conditions averaged over weeks to months and averaged over large areas; e.g. the chance of above average winter rainfall over western Europe, or the likelihood of an El Niño event in the Pacific. Such long-range predictions (seasonal forecasts) depend on the existence of relatively slow changes in the upper ocean temperatures. The ocean—atmosphere link is particularly strong in the tropics, for which seasonal predictions are usually more reliable than for mid-latitudes.

Seasonal forecasting with coupled ocean—atmosphere models requires information about the initial upper ocean state. However, apart from the TAO/TRITON and PIRATA moored arrays in the equatorial Pacific and Atlantic, observations of the upper ocean are sparse, and satellite (SST and altimeter) data are insufficient to provide adequate detail about the upper ocean structure. Consequently, data from Argo will benefit seasonal forecasting through allowing better initialisation of coupled ocean—atmosphere models. This should lead to improved long-term forecasts of wet or dry seasons and better warning of the likelihood of floods and drought for many areas of the world.

Climate Prediction

There is a constant exchange of heat, momentum and water between the ocean and the atmosphere. The ocean acts as a heat sink to delay climate change and ocean currents transport large amounts of heat and water around the world. The rate of change of climate is largely determined by processes in the ocean interior. In particular, the large thermal inertia of the oceans, and the consequent long time-scales of adjustment, means that an accurate representation of ocean processes is critical for realistic climate simulation and predicting climate change.

Western Europe is particularly influenced by the Atlantic Ocean. Variations in sea temperatures can influence its climate over periods of several years. Coupled ocean—atmosphere climate model simulations made by the Hadley Centre for Climate Prediction and Research (Wu and Gordon, 2002) have suggested the deeper ocean (below 500 m) influences the SST and NAO on decadal and interdecadal timescales. Also a change in the Atlantic thermohaline circulation could have a dramatic effect on Western European climate.

Argo is an important component of the GCOS, a long-term, user-driven, operational system for providing the comprehensive (atmospheric, oceanic and terrestrial) observations required for monitoring the climate system, for detecting and attributing climate change, for assessing the impacts of climate variability and change, and for supporting research toward improved understanding, modelling and prediction of the climate system. Recent climate simulations made by the Hadley Centre (Banks and Wood, 2002) suggest a freshening in southern Indian Ocean and Arabian Sea intermediate waters is a signal of anthropogenic climate change. Guided by these results, Argo floats are being deployed in these regions to monitor salinity.

PRESENT DAY ARGO FLOATS

Today's second-generation floats include the Sounding Oceanographic Lagrangian Observer (SOLO) (Davis, 2001), the Webb Apex and MARTEC PROVOR. The floats drift at a preset parking depth (typically 2,000 metres), returning to the surface every 10 days to give a temperature and salinity profile. When at the surface the floats relay their data and position to an orbiting Argos satellite before returning to depth and continuing another cycle, Figure 3. The expectation is that the floats should be capable of making as many as 150 profiles and operate autonomously for 4 to 5 years, dependent on parking depth and cycle time, but limited by battery power. With present communications the floats typically spend 6 to 12 hours at the surface transmitting data. With increased bandwidth it is hoped this can be reduced to about 1 hour. Reducing the transmit time will save battery power and also minimise the likelihood of sensor biofouling.

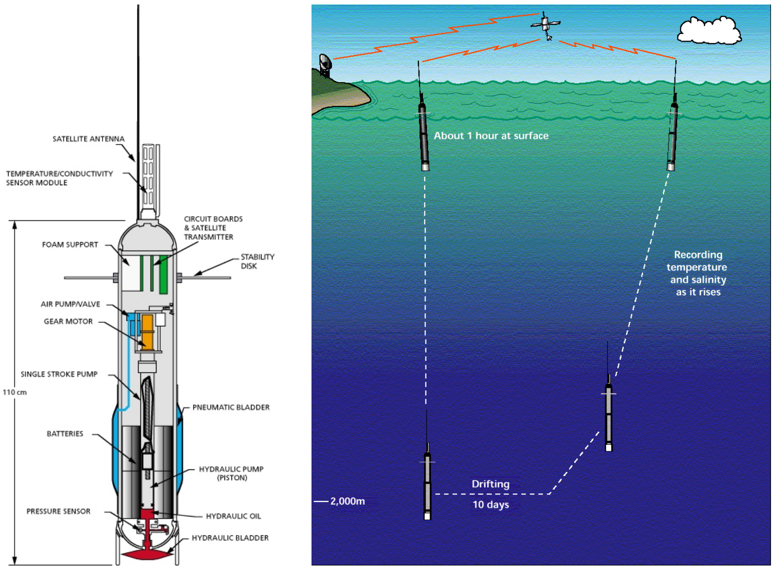

Figure 3. Left, schematic showing the main components of a float. Right, a typical profiling float cycle.

Float deployment

To date, the vast majority of floats have been deployed from ships. Usually, this is done from stationary vessels, under calm conditions, where the floats are lowered into the water using ropes. Floats have also been deployed by the University of Washington from VOS (Voluntary Observing Ships) during regularly scheduled transits across the Atlantic. These deployments have taken place with the ship at speed and from deck level, typically 20 to 80 feet above the water. The float is placed inside a cardboard box for protection and lowered into the water. The box is closed with lightweight cord and a water soluble link, once in the water, the link dissolves, allowing the box to open and discharge the float. VOS deployments have also been made by the Met Office (UK) using a free-fall technique. Here the float is packaged for air deployment and launched into the water using a slide. Apex floats (which are air-certified by the US Dept of Defense) have also been deployed by the US Naval Oceanographic Office from C130 aircraft. For air dropping the floats are packaged in an air deployment container together with a parachute.

Figure 4. Left, University of Washington VOS deployment; centre, Met Office VOS (free-fall) deployment and right, air deployment (photograph courtesy of Webb Research).

AVAILABILITY OF ARGO DATA

In line with WMO Resolution 40 and IOC Resolution XX-6, all data from Argo are openly available without proprietary restrictions. Real-time data from Argo are disseminated via the WMO GTS within a day or so of collection. The GTS data are in WMO TESAC (FM 64-XI) format which permits a resolution of 0.01 °C in temperature and 0.01 part per thousand in salinity (psu). The full resolution data (with salinity to 0.001 part per thousand) are also generally available in near real-time via the internet.

The delayed-mode float data, after quality control and evaluation against other data holdings (moorings, floats, XBTs, climatology etc.), are expected to be available after about 3 months. These data will ultimately be lodged at the 2 designated global Argo data centres (the GODAE server, Monterey and Coriolis data centre, IFREMER, Brest) and specified regional data centres, and be available on web-servers for public access. The AST has established an Argo Data Management Group to ensure consistency of Argo data processing and formats across the various national, regional and international data centres. The procedures are being documented in an Argo Data Management Handbook.

ARGO INFORMATION CENTRE

To help co-ordinate Argo deployments the IOC, with support from interested Member States, has established an Argo Information Centre (AIC) with an Argo Coordinator. The Centre is located in Toulouse, France, and provides information to designated contact points in Member States about float deployments, how to track float positions, and how to access float data in compliance with the IOC Resolution XX-6. The AIC supports the international program in various ways; it provides liaison between float-providers and on float deployment opportunities, it acts as a clearing house for information on all aspects of float use, and promotes an improved dialogue between oceanographers and meteorologists, and between research and operational communities. The AIC also issues updated float lists, monthly status reports and monitors in real-time the status of Argo, see http://argo.jcommops.org.

ARGO 2002 - WHERE WE ARE NOW

Since its inception 3 years ago, Argo has developed rapidly with 310 floats (at 21st January 2002) reporting data (in addition to over 100 surviving pre-Argo floats). Figure 5 (produced by the AIC) illustrates the present coverage of Argo floats. Most of the floats are concentrated in the North and Tropical Atlantic and Pacific Oceans, with some floats in the Indian Ocean. There are as yet very few floats south of 30° S and none in the Southern Ocean. To achieve a uniform global float distribution, around two-thirds of all Argo floats will need to be deployed in the southern hemisphere. This will be a major challenge for Argo with most of its participants being northern hemisphere nations.

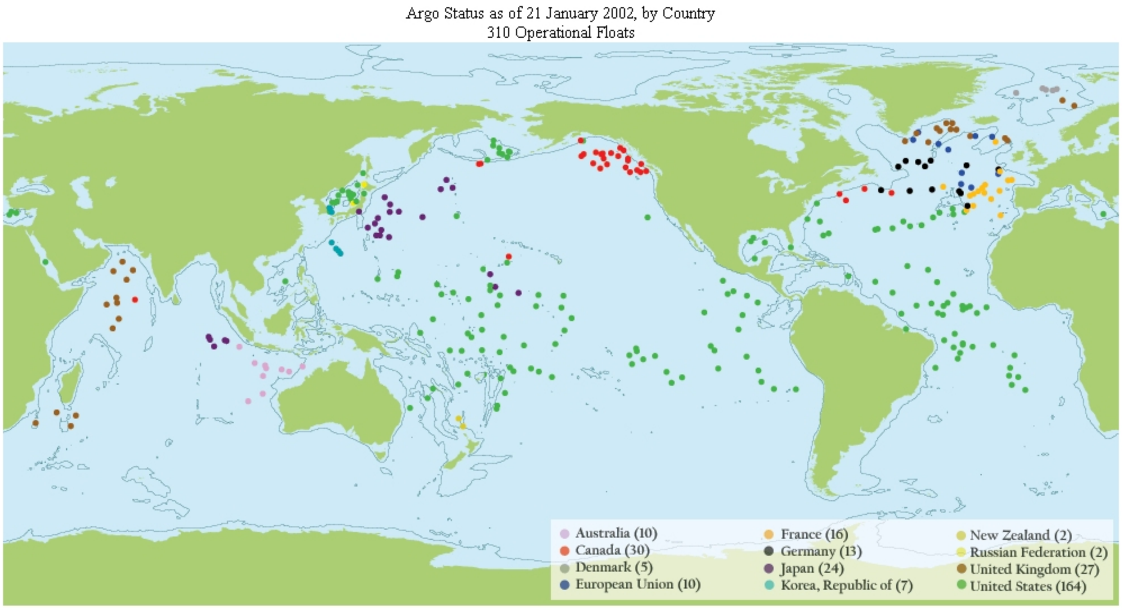

Figure 5. Argo status as at 21st January 2002.

Profiling floats are already making a significant contribution towards the amount of profile data available in real time, as shown in Figure 6. This shows the number of XBT profiles received in real time by the US NODC (National Oceanographic Data Center) during the 1990s, typically ~40,000 profiles are received per annum. During 2001/02 the number of profiles from floats is expected to be ~17,000, contributing ~30% of the total number of profiles. The full Argo array of 3,000 floats will deliver ~100,000 profiles per annum.

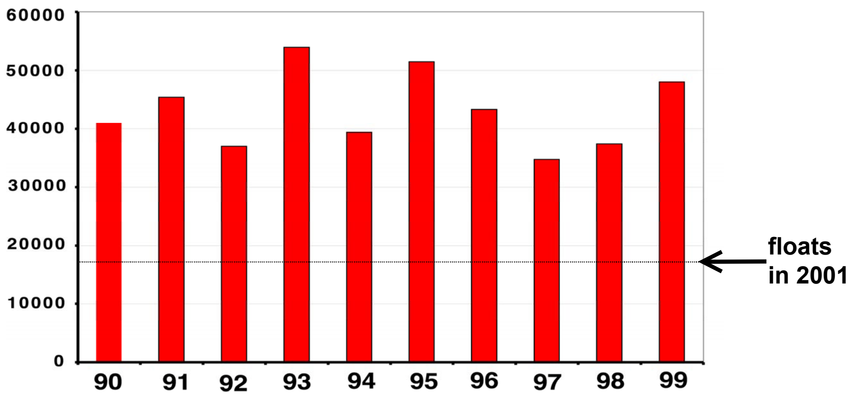

Figure 6. Showing the number of real-time XBT profiles received by NODC each year during the 1990s, and the number of float profiles currently being disseminated in real-time on GTS.

SUMMARY

Over the past 3 years, Argo has developed rapidly with expectations for the full global array being in place by 2006. The implementation of Argo is unique in both its pace and scope; it offers the first truly global observing system for the deep oceans and is bringing together research and operational organizations with a common goal. Argo currently has the status of a pilot project to establish a global float array, the hope is it will then enter a transition phase and become an operational system with nations committing longer-term funding. However, it will be essential for Argo to demonstrate real benefits and impacts for this to be justified.

Over the coming years, GODAE will provide a demonstration of, and quantify, the benefits of Argo for real-time ocean analysis and forecasting. However, it will take rather longer to demonstrate the impact of Argo on seasonal forecasting and climate prediction. As noted earlier Argo is expected to be an important component of the GCOS for long-term climate monitoring.

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WWW LINKS

Argo: http://www.argo.ucsd.edu
Argo Information Centre: http://argo.jcommops.org

GOOS: http://ioc.unesco.org/goos
GCOS: http://www.wmo.ch/web/gcos/gcoshome.html

Global Argo data servers

GODAE Server: http://www.usgodae.fnmoc.navy.mil
Coriolis Data Centre: http://www.ifremer.fr/coriolis/cdc
Japan Argo Real Time Data Base: http://argo.kishou.go.jp